ATOMICS

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A monthly journal devoted to the needs and interests of everybody concerned with the application of nuclear energy in all its various phases, in industry, in the medical and biological sciences and in the development of electrical power and heat.

ATOMICS

ANDREW W. KRAMER, *Editor*

The Perils of Being Important—At the Chicago meeting of the American Physical Society in November 1949, Dr. Samuel K. Allison, wartime Director of the "Metallurgical Laboratory" of the Manhattan Project and present Director of the Institute of Nuclear Studies at the University of Chicago, viewed with misgivings the recent rise of Physics to fame. For, as Dr. Allison pointed out, the state of physics today is good, indeed it is very good. The *Physical Review* is losing money—an excellent sign in itself. Its bimonthly issues bulge with learned contributions to knowledge.

Dr. Allison could remember, not so long ago, when all the sessions of the Washington meeting of the American Physical Society were held in small lecture rooms at the Bureau of Standards. The only physicist widely known then was Dr. Einstein.

Today it is different. Any young man who can call himself a nuclear physicist is besieged with requests to speak for women's clubs on the world political situation and the panel discussions on applied nuclear physics, if placed from end to end, would stretch from Los Alamos to Bikini.

Now, as Dr. Allison pointed out, physics has always been important. It gave us the basic discoveries which led to the development of such things as the generation of electrical power, modern X-ray technique, radio, etc. Unfortunately, it is not because of these benefits to mankind that physics finds itself in the ascendant position it occupies today. The principal motivating power behind the enormously increased support for physics in the last decade, said Dr. Allison, is the realization that physics and physicists are important for waging war. And since war is important, physics is important.

We all know what the physicists, together with the chemists and engineers, accomplished during the war—all the brilliant achievements in radar, ordnance, navigation, and atomic energy and, as Dr. Allison pointed out, no one in his right mind, then, or now, would state that these things should not have been done because they would associate physics with war in the popular mind, and, even worse, in the minds of the politicians. Physicists were caught in an inexorable procession of events which left them no choice; in fact, their duty was all too obvious.

The wave of response of physic-

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ists in America to the emergency was retarded in phase, but its amplitude, greatly augmented by the influx of scientists from the dictatorships, proved to be even greater than that abroad. The projects in which the physicists played an important role were astonishingly successful.

THE BIG BAD MEN

The bewildered public, Mr. Allison pointed out, was told that these things had been done by physicists, and in particular, in the spectacular case of the atomic bomb, by nuclear physicists. The great industrial companies, without whose organizing ability and technological know-how the nuclear physicists would have been helpless, avoided the spotlight of publicity as much as possible. They remembered that those who had supplied ammunition to our troops in World War I were, after a sudden reversal of public opinion, excoriated as "merchants of death," and accused of fomenting wars in order to market their products.

Dr. Allison pointed out that the physicists might have done well to use a bit of this caution.

Suddenly physicists were exhibited as lions at Washington tea parties and were invited to conventions of social scientists where their opinions on society were respectfully listened to by life-long experts in the field. They were asked to endorse plans for World government and to give simplified lectures on nuclear matters before Congressional committees. No wonder heads were turned.

DESTRUCTION OF THE CYCLOTRON AT TOKYO

But the extent to which physics had become important, said Dr. Allison, was not fully brought home until he was shocked by the news of the destruction of the cyclotron in Tokyo. Surely no physicist could have instigated this senseless act, or approved of the order which was issued to initiate it. The important and dangerous nature of physics was so obvious to some military officer that the cyclotron was cut to pieces in the same way that one would spike the enemy's guns or blow up his fortifications.

Dr. Allison said he considered himself a patriotic citizen of the United States, and when the country did something which seemed generous and wise, such as the distribution of radioisotopes to qualified scientists everywhere, he felt a glow of pride. By the same token, when we behaved in a way which seemed unworthy, he felt ashamed. The Tokyo incident was shameful. Who would now believe in our pretensions of spreading knowledge and technical progress over the world? It could have been motivated only by petty malicious revenge to which civilized adults should not stoop.

BAD REGULATIONS

The same sort of thing is happening today in our regulations affecting the conduct of research in Germany. Dr. Allison quoted various articles in the Regulations in the U. S. Area of Control, which prohibit research wholly or primarily of a military nature. A conscientious military governor would have some very difficult decisions to make in attempting to enforce these articles and an advisory board of scientists could be of little help.

Unfortunately the kind of experimental physics in which we can expect fundamental and revolutionary discoveries is, today, very expensive and these projects have to be supported out of public funds. It is here that the greatest danger to the future of physics lies, for since the expenditure of

public funds is under the control of politicians who are easily swayed by the military, the projects for which money is allocated are hamstrung with stupid secrecy restrictions.

This matter of secrecy, Dr. Allison considered a very serious matter, and as a taxpayer he questioned the advisability of supporting secret research with his tax money.

EVILS OF SECRECY

The evils of secrecy fall into two headings:

1. Secrecy suppresses basic physical knowledge concerning the universe which should be used to stimulate thinking everywhere.

2. The existence of an inner core of secret facts vitiates whole areas of scientific inquiry and technological development extending far from the actually classified data. No one can remember from day to day just what is classified, and to be safe, avoids discussing whole fields of research and technology.

At the present time the harm done by the second of these two categories is probably worse than that done by the first. Concerning the first, there seems to be an unbridgeable gulf between the attitude of the scientist and that of many lawyers, politicians, and military men. As Dr. Allison explained, the hopelessness of the chasm was impressed on him during the war period when the situation was patiently explained to them in words of one syllable. When workers in an army ordnance plant make a howitzer, they are well paid for their work. The howitzer, however, does not belong to them. It is delivered, well crated, all parts checked and double checked, to the war department which uses it as it sees fit. In the same way the physicist is paid to obtain information which the Government wants. This information obtained by experiment or by calculation does not belong to him. He writes it up carefully and delivers it to the agency which pays his salary, and this ends the matter. This discourse, said Dr. Allison, had its intended effect. It reduced him to a state of speechlessness, and no reply was formulated.

Fortunately, the persons in charge of disbursements of government funds for research in physics do not operate on this highly simplified procedure, and an earnest effort seems to be made in the AEC to declassify basic researches within the directives given by Congress. Nevertheless, certain information concerning the details of the fission process, and eminently suitable for publication, remain secret, and, therefore, sterile. Who can say that these facts, if known to another Yukawa or another Dirac, might not prove the missing link in the formation of a successful theory of nuclear forces.

In a recent radio round table, one of Dr. Allison's colleagues advocated the removal of secrecy from many of the activities of the AEC. An ex-military officer present concisely summarized his objections as follows: "This is childish. Why help the Russians?" This argument could have been used to prevent the publication of the structure of penicillin, or of the physicological properties of cortisone. Who can guarantee that these items of information may not help the Russians to invent more horrible forms of bacteriological warfare?

The requirements of secrecy, not to be confused with security except in some military minds, prevent any open and effective discussion of the feasi-

bility of breeding, which will probably be vital to the large scale peaceful application of nuclear energy. Dr. Allison said he knew from experience in Chicago, with engineers of the Commonwealth Edison Company, that they were eager to learn about, and discuss, such problems.

THE ONR-AEC PROGRAM

There was one bright element in Dr. Allison's rather dark picture. University physics is being extensively supported from public funds under a program initiated by the Office of Naval Research, and recently made a joint program, with the AEC participating. This program has had remarkable success. Many physicists, at first, looked at it askance, being sponsored by Navy funds, but soon rejoiced to find that these funds were allocated with an understanding of the needs and customs of universities and of scientists carrying out basic researches. The strong and politically minded Navy Department has thus far successfully prevented uninformed politicians from insisting on the introduction of secrecy and guilt-by-association investigations into a region where there is no reason to strangle the geese that laid the plutonium eggs.

But how long will it be before secrecy seeps into the ONR-AEC? How long will the AEC be permitted to have its own unclassified projects? Dr. Allison was apprehensive and so he urged scientists to be more vocal in expressing their approval of the enlightened support being received from the joint ONR-AEC program. Representatives in Congress should be told of the success of the plan and scientists should express the hope that the administrative procedures initiated here will be carried out in a National Science Foundation, if that should be set up in the future. We should let the public enjoy with the scientists the progress of physics and its discoveries. We should justify physics as a worthy intellectual activity in a world at peace.

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Nuclear Power Engineering

Part VIII* Radioactivity; Its discovery and implications . . . Roentgen's discovery of X-rays . . . Influence of discovery of X-rays upon discovery of radioactivity by Becquerel . . . Character of radioactive radiation . . . Alpha, Beta, and Gamma rays . . . Alpha ray effects . . . Surface effect in Alpha ray emission . . . Nature of alpha and beta rays . . . Radioactive series . . . Origin of radium . . . Nature of gamma rays . . . Artificial Radioactivity . . . Nuclear reactions in radioactivity.

By ANDREW W. KRAMER

IN THE PRECEEDING three installments of this series we have considered several aspects of nuclear structure and of the forces operating in the nucleus. Although the nucleus is composed of only two entities, protons and neutrons, it must be quite obvious from even this preliminary consideration of nuclear structure and forces that explanation of nuclear reactions involves many complications, the intricacies of quantum mechanics, for example.

Before we consider further aspects of nuclear behavior as related to the influence of external particles, it is desirable that we should consider nuclear transformations which occur spontaneously in the nuclei themselves, that is, the subject of *radioactivity*.

Historically, the first nuclear transformations that were observed were in the phenomenon of radioactivity. Radioactivity was discovered by Henri Becquerel in 1896. This discovery was the consequence of a more or less accidental series of events which occurred in the preceeding year. About a year earlier, W. C. Roentgen had discovered x-rays. In his experiments with electrical discharges through evacuated tubes he had noticed a phosphorescent glow on the walls of his tubes as well as on a platinum barium cyanide screen placed at some distance from the tube. Then this glow was known as phosphorescence, now, we call this action fluorescence. In further experiments he found that the interposition of various thicknesses of different substances between the screen and the tube reduced the intensity of the fluorescence but did not obliterate it completely. This showed that these *X-rays,* as Roentgen called them, had very great penetrating power. Further experiments showed that they could blacken a photographic plate, and ionize a gas.

Roentgen traced the source of the X-rays to the walls of the tube. When an electric discharge is produced in a tube operating at a low gas pressure, the positive ions of the gas bombard the negative electrode and cause it to emit electrons. These electrons, or cathode rays as they are called, are attracted towards the anode and in a short space acquire a very high speed. Some of them are absorbed in the anode but others strike the walls of the tube and cause the glass wall to emit x-rays. In modern tubes nearly all of

*Through error the December installmest of this series was designated Part VIII. It should have been Part VII.

the x-radiation is produced not in the glass but by the electrons bombarding the anode itself.

BECQUEREL'S INVESTIGATIONS

Shortly after Roentgen's discovery, physicists all over the world began to experiment with these mysterious rays which would pass through solid matter. Henri Becquerel, on the other hand, was led to a different mode of investigation. As already stated, the walls of Roentgen's tubes fluoresced, that is, they emitted visible radiation. He had previously been working with fluorescent salts and, so, decided to investigate the relationship between fluorescence and x-rays. He proceeded to investigate these salts to see if they would emit x-rays after they had been made to fluoresce by exposure to sunlight. The results of these experiments were unsuccessful in all but one instance. In this instance he had used a salt consisting of uranium and potassium sulfate. On February 24, 1896, Becquerel reported his first results: after exposure to bright sunlight, crystals of potassium uranyl sulfate emitted a radiation which blackened a photographic plate after penetrating black paper, glass and other substances.

During the next few months he continued his experiments, obtaining more and more puzzling results. The effect was as strong with weak light as with bright sunlight. Finally, he discovered that the action took place in complete darkness even for crystals prepared and always kept in the dark. Previous exposure to light obviously had nothing to do with the action.

This strange radiation was emitted by other uranyl salts and by solutions of uranium salts, even by what was believed to be metallic uranium, and in each case the intensity of the radiation was proportional to the uranium content. Since Roentgen's x-rays had been shown capable of ionizing gases and thus discharging electroscopes, Becquerel was led to try

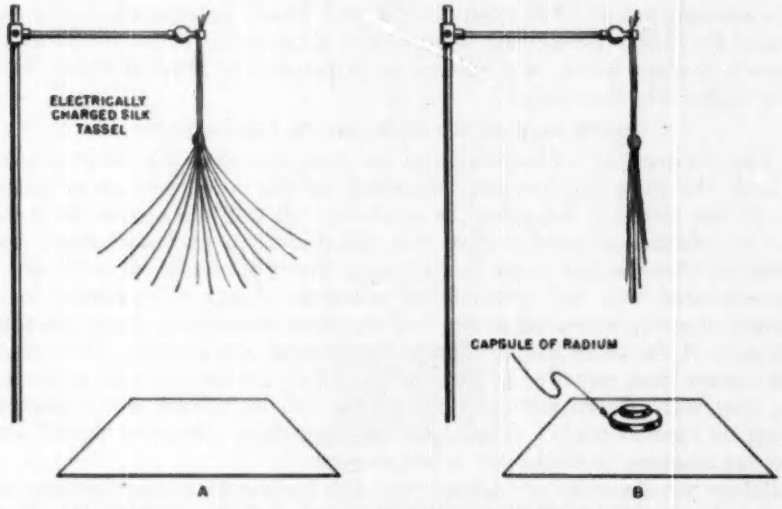

Fig. 1. Drawings made from photographs showing the electrical effect of radium At (a) is shown an electrified silk tassel. Since all threads have similar charges they repel one another. At (b) is the same tassel after a capsule of radium has been placed underneath it. Due to the property which radium rays have of making the air electrically conducting, the threads of the tassel have collapsed

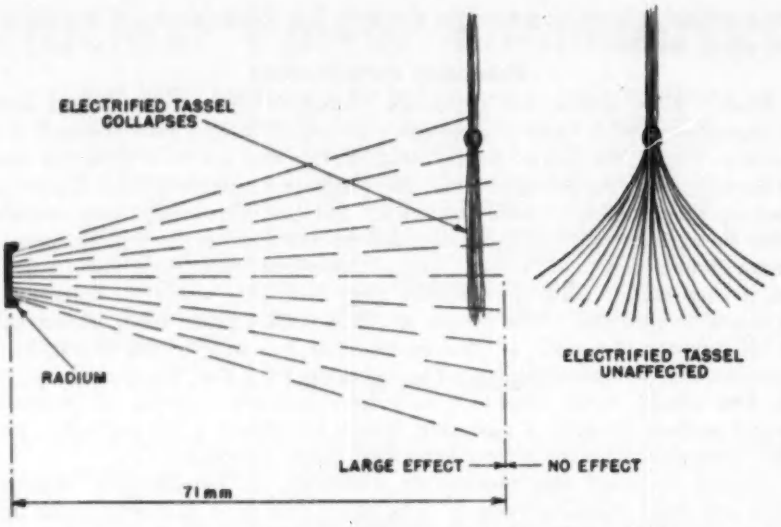

Fig. 2. Showing the very definite range of the alpha particles
Up to a distance of 71 mm. the intensity of action is quite strong, but at this distance it ceases abruptly. The electrified tassel just beyond 71 mm. is unaffected but when moved to just within this distance from the radium it collapses almost at once.

similar experiments and found that the ray from uranium behaved in similar fashion. All this work was done in the early part of 1896. Although Becquerel and other investigators continued work in this direction for several years, the knowledge gained in this phase of the new science was summarized in 1898 when Pierre and Marie Sklodowska Curie concluded that the uranium rays were atomic phenomena, characteristic of the element and not in any way related to its chemical or physical state. Thus, they called it *radioactivity*.

SIGNIFICANCE OF THE DISCOVERY OF RADIOACTIVITY

The discovery of radioctivity was the most amazing, the most startling, indeed, the most revolutionary discovery in the entire history of science for at one stroke it compelled us to change all our conceptions of matter and its relation to energy. Not only did it exert a profound effect upon scientific theories but upon our thought and philosophy as well, for it demonstrated that the principle of universal change so apparent in all aspects of nature extended to the very elements themselves. Since the futile attempts of the alchemists to change one element into another, the elements had always been regarded as immutable. With the discovery of radioactivity, they were shown not only changeable but the process was apparently going on spontaneously! That such an astonishing discovery should have had far reaching consequences is not strange.

Before the discovery of radioactivity, our knowledge of the elements was extremely superficial. True, much was known of chemical reactions and by the periodic law, the known elements had been classified according to their atomic weights. The atoms, it was known, were the *bricks* of which the universe was constructed and, while much was known in regard to the results effected through various combinations of these bricks, little or

nothing was known of the bricks themselves. Atoms were thought to be indivisible. Even so, many suspected that atoms *might* be composed of still smaller particles. There had never been any evidence of such particles, however, and, had any one ventured to predict radium 60 years ago, he would have been told that such a thing was not only improbable but contrary to all established principles of matter and energy.

As Soddy[1] puts it, if one were to demonstrate to an architect or builder, that the bricks he habitually used in the construction of his buildings were under other circumstances, capable of entirely different uses, say, for instance, of being used as explosives far more powerful than dynamite, his surprise and astonishment would be no greater than was the chemist's at the new and undreamed of possibilities of matter as demonstrated by the mere existence of such an element as radium.

Radium, it was shown, was some two million times more radioactive

[1]The Interpretation of Radium. By Frederick Soddy.

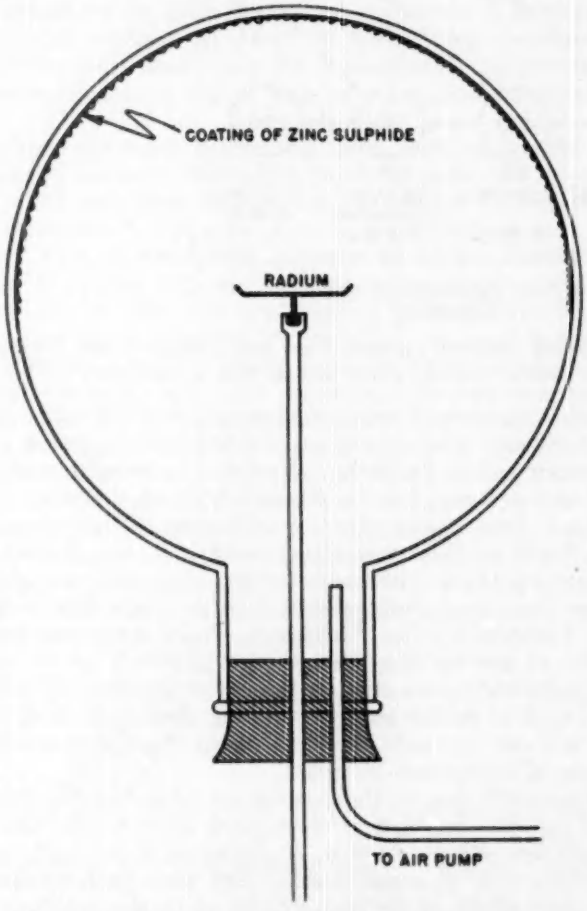

Fig. 3. Experiment to show the range of alpha particles in air

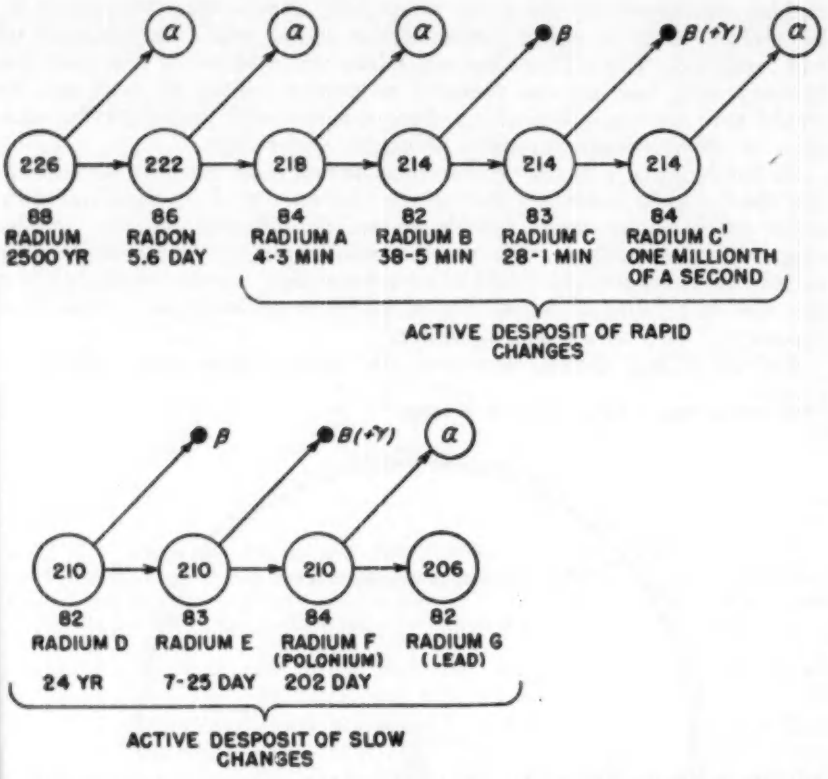

Fig. 4. Steps in the successive transformations from radium to lead. The radium itself is the result of previous transformations from uranium shown in Fig. 5

than uranium. As intensive work went on all over the world in the early years of the century, other of the heavy elements were found to be radioactive in greater or less degree but all of them were characterized by the emission of one or more of three different types of radiation, which were named alpha α, beta β, and gamma γ radiations. These three radiations differed markedly in their penetrating power. It was discovered that a certain proportion of the total radiation was completely absorbed by very thin screens—even by a sheet of thin paper or by a few centimeters of air. These, Rutherford called Alpha rays. A far more penetrating radiation,, capable of passing through several millimeters of aluminum, was called Beta radiation or beta rays. A third type, subsequently called gamma rays, were found to be far more penetrating than even the beta rays for their effect was not lost until they had passed through as much as 20 cm of iron or several centimeters of lead.

The striking difference in the penetrating power of these three classes of radiation led the investigators to examine more closely the nature of each of these three classes. At first, it seemed as if the feebly penetrating alpha rays were of little consequence. They were easily stopped by thin screens and their effects on the photographic plate was small in comparison with the effect of the beta rays.

To the electrical test, however, that is the discharge of an electroscope, the alpha rays were found to be immensely more effective than both the beta and the gamma rays together, and from this fact Rutherford concluded that the energy possessed by these feebly penetrating alpha rays is always immensely greater than the other two types of radiations taken together. This fact was borne out in later researches, in fact, the beta and gamma rays at most possess but a few per cent of the total energy of radiation and are in this fundamental respect of less consequence than the previously neglected alpha rays.

ALPHA RAY EFFECTS

In Fig. 1 are shown two drawings made from actual photographs illustrating the electrical effect. At (a) is shown an electrified silk tassel suspended from an insulating support. The tassel has been stroked by a rubber tobacco pouch and is electrified. All threads having similar charges, they naturally repel each other and stand out as shown.

Now, suppose, while the tassel is thus electrified, a capsule of radium bromide is placed on the table underneath the tassel. The moment this is done, the threads collapse as shown at (b). This experiment is very striking and illustrates beautifully the ionizing power of the radium rays. We now know, of course, that a beam of x-rays could produce a similar result.

To show that the feebly penetrating alpha rays are largely responsible for this electrical discharge effect, it is necessary to touch upon certain considerations which come into play because of their great absorption in passing through matter. In the first place, radioactivity is a mass or volume phenomenon. That is, every part, not only the surface but the inner portions also, of a radium salt, for example, is giving off alpha, beta and gamma rays. All of these rays are absorbed by the substance itself, very considerably, but this absorption does not effect the more penetrating rays (beta and gamma) nearly so much as the feebly penetrating alpha rays. That part of the latter generated inside the salt does not escape at all. Only a very thin film at the surface contributes to alpha radiation. The consequence is that, while with the small quantities of radium available for study, the strength of the more penetrating rays is more or less proportional to the quantity of radium employed, for alpha rays this is not the case. For the alpha rays, the effect is proportional, not to the weight or mass of the substance available but rather to the amount of surface exposed. An exceedingly small quantity of radium bromide, spread out as a thin film on a large plate, will give immensely more alpha rays than the same quantity in the form of a crystal.

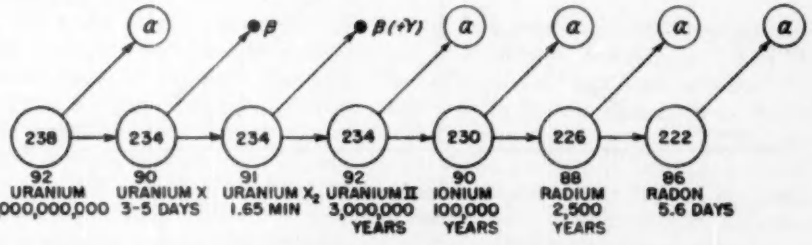

Fig. 5. Successive transformations of radioactive elements from uranium to radon

As already mentioned, to separate the beta and gamma rays from the alpha rays it is merely necessary to interpose between the radium a screen of cardboard of sufficient thickness until all the alpha rays are screened out. The separation of the beta and the gamma rays can, of course, be effected in a similar manner, only much thicker screens are necessary.

It will be evident, however, that to separate the alpha from the beta and gamma rays this method of separation does not apply, for any screen that removes beta and gamma rays removes much more of the alpha rays.

SURFACE EFFECT IN ALPHA EMISSION

To separate the alpha rays, therefore, use is made of the surface phenomenon referred to. If a very minute quantity of radium salt is spread over a large area, the beta and gamma rays from so small a quantity will be practically negligible, whereas the alpha rays under these conditions will reach their greatest intensity. For practical purposes, this film of pure radium salt can be used to give alpha rays by themselves, essentially free from the beta and gamma rays.

To show the range of the alpha rays in air, Professor Bragg devised a very striking experiment which can be demonstrated in any laboratory possessing a small quantity of radium bromide. The alpha rays, remember, are stopped by a few centimeters of air—that is, they are absorbed entirely in passing through such a small thickness of air. What is so striking about this experiment is not the fact that a small amount of air is sufficient to effect complete absorption, but the suddeness with which this effect occurs. Each individual alpha ray from a particular radioactive element[2] travels exactly the same distance in a homogeneous absorbing medium and is stopped sharply and completely when a certain thickness of matter has been penetrated. As a consequence, if we measure the effect of a homogeneous beam of alpha rays just outside the distance of complete absorption, there is absolutely no effect, while just within there is an extremely large or powerful effect. This is shown in Fig. 2.

Another way of demonstrating the very definite range of alpha particles in an absorbing medium is by the apparatus shown in Fig. 3. This is a diagram of a flask, slightly more than 6 in. in diameter and coated on the upper hemisphere of the inside surface with a film of zinc sulphide. This film fluoresces brilliantly when exposed to the direct action of a beam of

[2]There is a difference in the penetrating power of alpha rays from different radioactive materials. Thus, the range of alpha rays from radium is different from the alpha rays of say thorium or uranium.

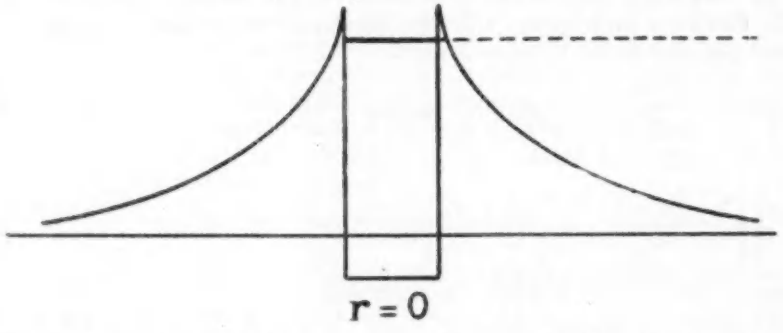

Fig. 6. Diagram of the potential energy of an alpha particle in the field of a nucleus.

alpha rays. In this experiment the flask is so arranged that a platinum disk coated with an extremely thin layer of radium salt, (prepared by evaporating down a solution containing about a milligram of pure radium bromide) can be moved up and down inside the flask, the disk being held centrally by means of an air tight stopper.

Assume that the room is darkened. In the dark, the flask, being full of air at atmospheric pressure, can scarcely be observed; there is no glow. The three inches of air between the radium surface and the chemical coating on the inside of the flask entirely absorbs the alpha rays and practically all of the beta and gamma rays of which there is only a negligible amount. It is only necessary, however, to connect the flask to an air pump and commence to reduce the air pressure for the zinc sulphide film to start glowing. At the first stroke of the air pump the whole globe flashes into luminescence and as the pressure is further reduced, this luminescence becomes stronger. Due to the reduced air pressure, the alpha rays are not now subject to so much absorption and the rays reach the surface of the globe. As soon as the air is readmitted, the luminescence ceases as suddenly as it appeared.

NATURE OF ALPHA AND BETA RAYS

Thus it is seen that the range of the alpha rays is something that is very definite. This peculiar property gave the early investigators a clue as to what these rays were for it appeared that this radiation was not subject to the same laws which govern the dispersion of light and x-rays. Today, after years of study and research we know that this is true; we know that the alpha and beta rays are not like rays of light but consist of particles traveling at enormous velocities. This fact, that these rays were shown to be particles, was one of the chief lines of evidence that radioactivity is a manifestation of atomic disintegration, for these particles must be emitted at the expense of the material of the atoms themselves.

As is well known now, in time these alpha rays were shown to be charged atoms of helium hurled out of the radium nucleus with velocities of some 10,000 miles per second. This accounts for their definite range for since they all have the same mass, the distance which they can travel through a material which impedes their progress naturally is a direct function of their initial velocity. In some elements, the explosion, so to speak, which hurls them out of the atom is considerably greater than in other elements. In the case of thorium C, for example, the range of the alpha particle in air is 8.62 cm but in uranium I it is 2.7 cm. The explosive force responsible for the projection of the alpha particle from thorium C is considerably greater than it is in the case of Uranium I, although the alpha particle is exactly the same in both cases. It consists of the nucleus of the helium atom.

Now, the helium nucleus it will be recalled consists of two protons and two neutrons, and its atomic weight is a little over 4. Actually it is 4.0028. So it would be expected that after the alpha particle has been expelled the radium nucleus would be about 4 units less in weight than it was before the emission. And this, of course, is the case; when a nucleus of radium with atomic weight 226 throws off an alpha particle it loses 4 units of weight and two (represented by the two protons in the helium nucleus) of electric charge. Thus, it becomes radon, with atomic weight 222 and atomic number (charge) 86. Radon is also called radium enanation.

The radon in turn emits an alpha particle and thus becomes radium-A

with atomic weight 218. This, again, loses an alpha particle and becomes radium-B with atomic weight 214.

When we reach radium-B, the next successive step in the disintegration process, a different action takes place. Instead of emitting an alpha particle, radium-B emits a beta particle which is an electron. Now, the emission of an electron can only change the atomic weight of the parent nucleus very little but since the electron represents a negative electric charge of 1 which is equivalent to receiving a positive charge of 1, the result of the beta particle emission is radium-C with the same atomic weight as radium-B but with atomic number 83.

And so on, the disintegration proceeds in successive steps as shown in Fig. 4 until radium-G, which is lead, is reached. It is unnecessary to explain all these steps in detail since the diagram is self-explanatory. It will be noted that there are two series of changes, one, through radium A, B, C, and C' which are rapid and another through radium D, E, and F, which are slow.

RADIUM STEMS FROM URANIUM

The radium 226 shown in Fig. 4, itself is the product of a previous series of transformations beginning with uranium 238. These transformations are shown in Fig. 5. As shown the average life of the uranium atom is eight billion years; that is at some time during a period of some eight billion years such an atom is liable to become unstable and emit an alpha particle. When it does it becomes uranium 234 which has an average life of only 35.5 days. This atom, therefore, can look forward to an existence of only about a month. This atom, when it becomes unstable, does not emit an alpha particle but a beta particle; that is, an electron. This, as already explained, does not change the atomic weight but it does increase the atomic number, making it 91. This is obvious when it is remem-

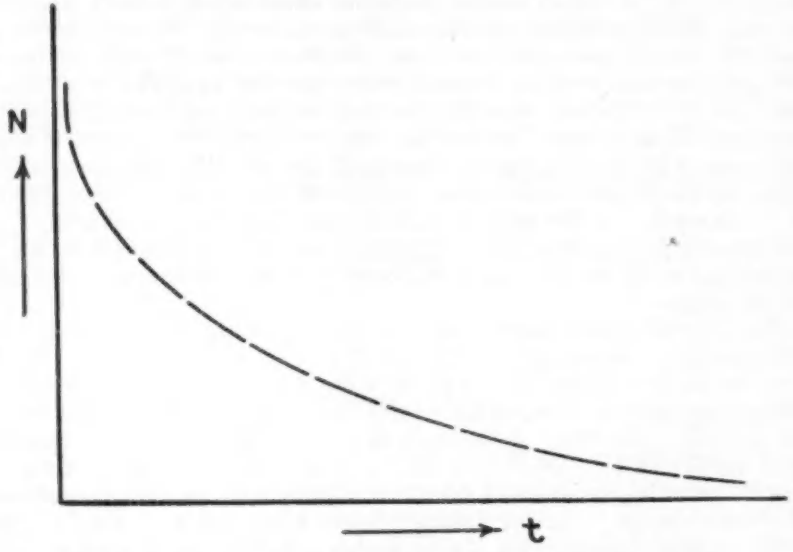

Fig. 7. Exponential relationship between number of nuclei and time

bered that the electron carries an electric charge of one. Thus, since the negative charge of one is lost, the total positive charge on the nucleus is increased by one.

Almost from the first, it was evident that the emission of the alpha particles from radioactive substances at such enormous velocities represented a great deal of energy. Early experiments in the exact measurement of the heat evolved by a minute quantity of radium proved this. The quantity of energy evolved was truly astonishing. Here, in radium we had an element evolving a perennial supply of energy, year after year, century after century, without stimulous and apparently without exhaustion. The mysterious radiations from radium seemed to upset the very law of the conservation of energy.

In time, however, the nature of radioactivity became known. We found that the enormous quantities of energy manifested by radioactive materials were actually stored in the heart, in the nucleus, of the atom and that the nucleus, instead of being a simple homogeneous particle, was in reality a complex thing in itself. We have already touched upon many aspects of nuclear structure, especially as it is affected by bombardment by external particles but in the phenomenon of radioactivity changes in nuclear structure occur spontaneously.

NATURE OF GAMMA RAYS

So far, we have described only two of the three types of radiation from radioactive substances. The first, that is the alpha rays were shown to be helium nuclei and the second, beta rays were discovered to be electrons. These electrons are hurled out of the nucleus at speeds of 75,000 to 150,000 miles per second. The third form of radiation, that is, the gamma rays, are not particles; they are a true electromagnetic radiation, in fact, gamma rays are x-rays of exceedingly high frequency and therefore of high penetrating power. The gamma radiation does not indicate a change in the nuclear structure, it indicates merely a settling down of a nucleus from a higher energy state into a lower, more stable state. It usually follows some other reaction and is accompanied by no chemical change of the substance.

One of the remarkable things about radioactivity is the fact that the alpha active substances take so long a time to emit the alpha particle. The average life of radium, as already indicated is over 2000 years.

In Fig. 6 is shown the diagram of the potential energy of an alpha particle in the field of a nucleus. This is similar to diagrams previously shown in other chapters. At great values of r, the interaction between the alpha particle and the rest of the nucleus of electrostatic repulsion—the Coulomb force discussed in earlier chapters. At small distances, the *stickiness* of the nucleus will cause the potential energy to be lowered, and near $r = O$, we find a *potential well.* The horizontal line not far below the top of the well represents the energy level which the alpha particle occupies at very high r values. This energy level in a radioactive nucleus is higher than the potential energy at very high r values. This must be so because we know that at high r values the alpha particle may appear carrying considerable kinetic energy, which kinetic energy must be derived from the energy that the alpha particle originally possessed in the nucleus, but in order that the alpha particle should escape the nucleus (moving along the dotted line in the diagram) it must cross a region of high potential energy. According to

classical mechanics this is impossible. As we have seen, however, in quantum mechanics the fuzziness of particles makes penetration through the potential barrier possible but the probability of the particle leaking through is very small. This is particularly true if the potential barrier is high. It has been found that the average time which the alpha particle is supposed to spend in the nucleus before leaking out by the quantum mechanical method is in fair agreement with the times actually observed. The sensitive dependence of this time on the height of the potential barrier explains why radioactive-decay times vary from a small fraction of a second to the billions of years inherent in uranium.

The mathematical law of radioactive decay is based on the fact that each radioactive nucleus has a constant probability of decay. This probability of decay is independent of the time the particular nucleus has already lived. Thus, in a group of radioactive nuclei, the number decaying per unit of time is proportional to the number of nuclei present. If we plot the number of nuclei as a function of time as in Fig. 7, we find that the resulting curve is an exponential one and the number of nuclei can be calculated by the formula:

$$N = N_o e^{-\lambda t}$$

In his expression N_o is the original number of neutrons (which were present at $a = O$) and λ is the reciprocal of the so-called mean life. Of course, some nuclei live shorter, and a few considerably longer than this mean life. It has become more usual to describe the radioactive decay in a substance by the half-life. This is given by:

$$\text{Half-life} = 0.693 \div \lambda$$

The half-life, of course, is the time in which half of the original number of nuclei has decayed.

ARTIFICIAL RADIOACTIVITY

So far we have considered only the natural radioactive elements. As a consequence of the investigations done in the early thirties by the Juloit-Curies, today, by bombardment it is possible to make almost any of the elements radioactive. This is called artificial radioactivity. Artificially radioactive elements obey the same laws as naturally radioactive ones but while many beta-active substances have been produced artificially, artificial alpha activities are very rare.

A well-known artificial beta-active substance is obtained by bombarding the one stable isotope of sodium by deuterium. Thus:

$$Na^{23} + H^2 \rightarrow Na^{24} + H^1$$

The Na^{24} nucleus so obtained decays according to the equation

$$Na^{24} \rightarrow Mg^{24} + e^-$$

In this equation e^- is used instead of beta in order to show that a negative electron is emitted. The nucleus produced in the reaction, that is the magnesium nucleus, has one more charge than sodium and thus the total charge is conserved.

Now, the nucleus of any atom, we have said, is composed of only two entities, protons and neutrons; in fact, in explaining the work of deBroglie, it was pointed out that there was no room in the nucleus for electrons.

How, then, one may ask, is it possible for a nucleus to emit an electron? The only way we can account for this is to assume that the emitted electron

is created in the beta disintegration process. This is not an unwarranted assumption because we have other examples of the creation of particles. One example is the creation of electron positron pairs from radiation. This was discussed in Part IV.

The elementary creation process in beta activity is the reaction

$$n \rightarrow p^+ + e^-$$

The energy delivered to the beta particle is partly due to the mass difference between the proton and the neutron (0.0013 mass units) and partly it is drawn from the energy store of the beta active nucleus in which the neutron was originally formed. This simple process is exothermic. It is assumed that the neutron itself is beta active. This activity however, takes a longer time than other processes by which neutrons can disappear and therefore the beta activity of the free neutrons has as yet not been observed.

In the reaction just described a negative electron was emitted. In some cases a positive electron is emitted. Thus:

$$N^{14} + H^2 \rightarrow 0^{15} + n$$

The oxygen 15 nucleus resulting from this reaction decays according to the equation

$$O^{15} \rightarrow N^{15} + e^+$$

Here, it will be noted a positive electron is emitted. This type of reaction is more rare than the one emitting a negative electron and it does not occur at all in the naturally radioactive series. In this instance, the elementary reaction is

$$p^+ \rightarrow n + e^+$$

And this time, the elementary reaction is endothermic. This means that a proton is stable and a positron can be emitted only if the energy store of the beta active nucleus can supply sufficient energy to overcome the mass difference between the proton and the neutron.

It sometimes happens that a nucleus instead of emitting a positive electron absorbs one of the inner electrons of its own atom. This is usually one of the so-called K electrons. This process requires a smaller amount of energy than the emission of a positron because of the mass, and therefore, the corresponding energy of the positive and negative electrons. In principle it would be possible for a nucleus to capture a positive electron but even the capture of a negative electron is an improbable process despite the fact that the electron is near the nucleus all the time. Positrons are extremely short lived and so it practically never happens that a positron on its brief passage near a nucleus is absorbed.

While there is a great deal more to be said on the subject this provides a brief explanation of the phenomenon of radioactivity and it will enable us to understand better the induced nuclear reactions to be considered in later chapters.

(*To be continued*)

Instruments and Measurements in Atomic Power Plants

Unusual problems in the operation of proposed atomic power plants impose severe instrumentation requirements. In this article which is essentially the full text of a paper presented by the authors at the 1949 semi-annual meeting of the American Society of Mechanical Engineers, they consider the instrument requirements of the atomic power plant now being constructed at the Knolls Atomic Power Laboratory near Schenectady. This Laboratory is operated by the Research Laboratory of General Electric Co. for the U. S. Atomic Energy Commission.

By D. COCHRAN and C. A. HANSEN, JR.

Knolls Atomic Power Laboratory

THE ATOMIC POWER plant to be constructed for the Atomic Energy Commission at the Knolls Atomic Power Laboratory in Schenectady probably will be the first to generate useful electric power in more than token amounts. This is an experimental plant whose purpose is to investigate power production on a practical scale. It will also be used to investigate the possibilities of breeding. This plant employs liquid-metal reactor coolant and steam-turbo-electric power-generation equipment. The discussion presented here is related to such a plant as shown schematically in Fig 1.

The reactor is an assembly consisting of jacketed nuclear-fuel elements, control elements, moderating material, and reflecting material, all supported and positioned in a structural matrix. The liquid-metal coolant is pumped through channels in the reactor core, where it receives heat from the fuel elements. Leaving the reactor, the coolant passes through heat exchangers where it gives up heat to evaporate and superheat steam. The steam drives a turbogenerator to generate electric power.

The heat-generating nuclear reaction in the reactor core causes tremendous radioactivity which must be confined by an absorbing shield. The liquid-metal coolant passing through the reactor core becomes radioactive because of its exposure to neutron flux. Thus the piping, pumps, heat exchangers, and storage tanks which carry the radioactive coolant also must be shielded, although to a lesser extent than the reactor core. The radioactivity of the coolant does not cause radioactivity in the water and steam passing through the heat exchangers; hence it is not necessary to shield the steam and water piping and equipment in the power plant.

The reactor coolant leaves the reactor at temperatures high enough to permit an efficient steam cycle. Liquid metals have relatively low vapor pressures, however, and can be maintained in the liquid phase at pressures of a few atmospheres throughout the circuit. Hot liquid metals oxidize readily in contact with air, forming compounds harmful to operation as a

coolant. To prevent oxidation, it is necessary to maintain a blanket of inert gas over free surfaces of liquid metal wherever they occur.

There are remotely controlled mechanisms for actuating control elements, for removing spent fuel elements, and for inserting fresh ones. The sepnt fuel elements are intensely radioactive, and must be transported, stored, and processed in shielded spaces by means of remotely controlled machinery.

INSTRUMENT FUNCTIONS

Operation of this plant requires much elaborate instrumentation. Most of the instruments are standard commercial devices as, for example, those on the steam turbine, electric-generating equipment, and auxiliaries. Others must meet unusual requirements, and special designs are required. These can be classified according to the general function they perform as follows:

1. Operation: Instruments required for the control and safety of the plant operation.

2. Maintenance: Instruments to observe the condition and behavior of the reactor structure, fuel elements, coolant and blanketing gas as the operation of the plant proceeds.

3. Health: Instruments required to monitor radiation leakage in the plant to insure protection of operating personnel.

For plant operation there must be instruments to detect these quantities. Where possible a single instrument should be capable of covering the range indicated in the accompanying Table.

Health instruments must detect alpha, beta, gamma, and neutron radiation in exceedingly minute quantities, wherever it may leak through shielding or emanate from radioactive objects or from surfaces contaminated by radioactive substance.

GENERAL DESIGN REQUIREMENTS

In addition to requisite accuracy and sensitivity, a number of detecting devices in atomic power plants must meet requirements not found in conventional power-plant applications. These requirements arise from the radioactivity of the reactor and coolant and the shielding surrounding them. Typically, the shield may be several feet of concrete. The structure, equipment, and instruments within this radioactive zone are subjected to radiation of varying intensity depending on location. Some of these become permanently radioactive as a result of this exposure.

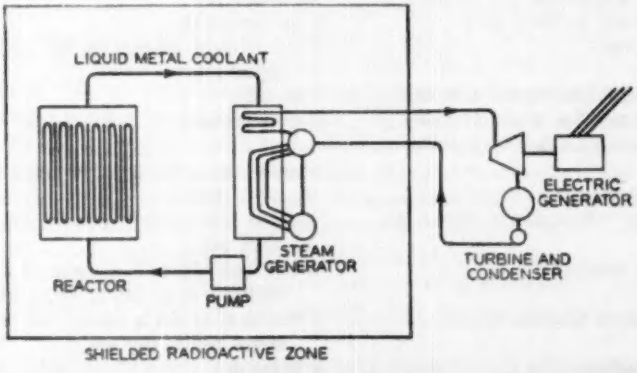

Fig. 1. Diagram showing the principal elements of a nuclear power plant

Some of the unusual requirements of instrumentation in the radioactive zone are as follows:

EXTREME DEPENDABILITY. It is essential that the nuclear reaction remain under control at all times. This is necessary to protect the reactor and associated equipment from damage, and to protect operating personnel in the plant from exposure to radiation from radioactive materials from the reactor. It is important here to note that, because of important differences in construction, it is not possible for a nuclear reactor in an atomic power plant to explode like an atomic bomb.

However, extremely dependable operating instruments, backed up by adequate safety controls, must be provided. Safety controls have been designed to stop the nuclear reaction. There is nothing about the nuclear reactor that corresponds to the safety valve of the steam boiler in a conventional power plant. In such a plant when there is a sudden increase in the rate of heat generation, or, as is more likely, a sudden decrease in heat absorption by the load, the extra energy in the boiler may be dissipated by blowing the safety valve. The nuclear reactor, however, has a definitely limited capacity for absorbing or dissipating extra energy. The instruments must sense abnormal conditions of heat generation or heat removal quickly and accurately to initiate appropriate action of the controls.

Of course no single instrument bears the entire responsibility for the safety of the plant. There are a multiplicity of detecting devices and a number of independent safety controls. Since an exceedingly high order of safety is to be achieved, these many instruments and controls are designed

INSTRUMENT RANGE

	RANGE
Neutron flux density in or near reactor core	10^7 fold
Control-element position	Within 0.005 in. over many feet
Reactor coolant temperatures	200 F to 1200 F
Reactor coolant pressures	—10 psi to 100 psi
Reactor coolant flow	0 to thousands of gpm
Coolant-liquid level	
Blanket-gas temperature	200 F to 1200 F
Blanket-gas pressure	1 mm Hg abs to 100 psi
To assist and guide maintenance, the following quantities must be detected or observed:	
Fuel-element temperatures	200 F to 1200 F
Internal pressures in reactor parts	A few atmospheres
Fuel-element rupture	Traces of fission products and fuel released into coolant stream
Core structure and fuel-element distortions	A few mils
Chemical contamination of reactor coolant	Very small amounts
Fission-product (radioactive) contamination of coolant	Traces of neutron flux in coolant remote from reactor
Chemical contamination of blanket gas	Very small amounts
Fission-product contamination of blanket gas	Traces of radioactivity in gas withdrawn from radioactive zone
Fuel-handling manipulation	Remote visual inspection of motions of a few hundredths of an inch to several feet
Location of stored spent-fuel elements	A fraction of an inch in channels and passageways several hundred feet long
Leakage of coolant	1 cc and up

to "fail safe;" so, an instrument failure shuts down the plant. Uninterrupted operation of the plant, therefore, requires reliability of all instruments and circuits.

Remote Maintenance. It is not possible to perform direct inspection and maintenance work on the detecting devices within the radioactive zone. They must be designed so that they can be checked and calibrated remotely, where this is necessary.

When a failure occurs, it may be necessary, because of radioactivity at the location of the device, to remove and replace it by means of remotely operated equipment. If the device has become radioactive in service, it usually cannot be repaired after removal, but must be replaced with a new unit.

Where the detecting elements are very difficult to remove or are completely inaccessible, stand-by detecting elements must be installed at the time of erection.

Neutron and Gamma Radiation. Pressure, temperature, and flow detectors must function correctly in the presence of tremendous radiation. Continued exposure to radiation must not cause such physical deterioration of the device as to change its performance in a way that cannot be determined and compensated for.

Devices to edtect chemical contamination of the coolant must function in spite of the radioactivity of the coolant.

Absolute Leaktightness. Detecting elements exposed to the coolant or blanket gas must be absolutely leaktight. The escape of even minute quantities of radioactive coolant or of blanket gas which might contain gaseous fission products might require that the plant be shut down and personnel evacuated until the leak could be located and repaired.

Long Service. Because of the extreme difficulty and expense of replacing faulty detecting elements, long operating life is much more important in these applications than is usually the case. There is great incentive to develop long-lived devices, and there is frequent justification for using more expensive devices to insure long service. A few situations exist where, once the reactor has been operated, detecting elements become absolutely inaccessible. Obviously, such arrangements are undesirable and much effort must be devoted to designing systems which avoid them.

INSTRUMENT APPLICATIONS

As previously stated, successfully demonstrated devices to meet these requirements have not as yet been developed for all the applications listed. Some of the devices upon which work is being conducted will be discussed.

Neutron Flux. Neutrons can be detected by measuring alpha radiation induced by their capture in boron. This is by means of ion chambers coated with boron or filled with boron-trifluoride gas. Boron atoms present a relatively large target for neutrons, and, upon capture, emit alpha particles which are powerfully ionizing in gas. Thus the capture of neutrons causes ion-current pulses between electrodes of the ion chamber which are readily discriminated from ionization caused by gamma radiation.

This discrimination is necessary because power generation in the reactor is directly related to neutron flux density, but not to the level of gamma radiation.

In operating the reactor, it is necessary to detect small changes in neutron flux over a range of 10^6 or 10^7 in intensity. Ion currents in the order of

micro-microamperes must be measured. To extend the range, several ion chambers may be used having different ranges by virtue of their location with respect to the reactor core.

A further requirement of the neutron-detecting systems is that they have an extremely rapid response time, in the order of milliseconds. This speed is necessary to actuate control elements or safety elements to compensate for sudden changes in reactivity in the reactor.

The principal limitations as to range and speed of neutron detection lie not in the ion chambers but in the associated circuits and relays. Present high-sensitivity amplifiers have high input impedance which imposes difficulties as to electrically insulating and shielding the leads to the detector so as to exclude spurious electric signals.

Finally, the neutron detectors must operate accurately and reliably at the high temperatures prevailing around the reactor core. This is a new requirement not found in the neutron detectors used in health physics work or in controlling low-temperature reactors such as those at Hanford which do not generate useful power.

PRESSURE. Measurement of pressure of the reactor coolant by means of Bourdon-type pressure gages with electrical telemetering is being considered. A gage fluid must be selected which will not suffer deterioration because of radiation exposure, and which will not contaminate the liquid-metal coolant. If blanket gas is used in the tube, there must be provision to insure its presence in adequate volume, regardless of pressure variations, entrainment, or dissolution in the coolant. Materials of the tubes must be corrosion-resistant and must maintain their elastic properties at high temperature.

Another type of pressure detector being investigated involves a thin diaphragm exposed to the coolant on one side and maintained in null position by a gas pressure on the other side. The balancing gas pressure may be measured remotely and the null position maintained by a needle valve actuated by the diaphragm so as to control the gas supply. This detector is relatively accurate and simple, but the thin diaphragm is thought to be a particularly vulnearable part of the coolant system. The diaphragm must be protected from overstress due to pressure surges, and there must be provision for stopping the escape of coolant in case of diaphragm failure.

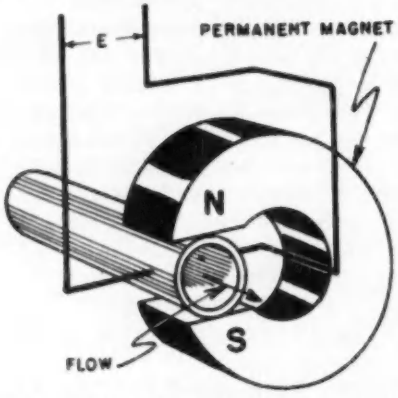

Fig. 2. Showing the principle of the electromagnetic flow detector

TEMPERATURE. Temperatures may be measured by means of thermocouples and resistance thermometers. Those measuring coolant temperatures are mounted in wells which must be tight, strong, and corrosion-resistant. Thermal contact with the ambient coolant must be good so that heat generated by absorption of neutrons and gamma rays in the sensitive element will be dissipated to maintain the element at the temperature of the coolant to be measured.

Electrical insulation of thermocouple wires in the radiation zone must be such as to resist damage from neutron and gamma radiation and high temperature. There is evidence that many organic insulations deteriorate rapidly in such environments. It is believed that quartz, glass, or ceramic insulations will give reasonably good service.

Measurements of temperature and pressure in the reactor core and fuel elements are important in determining the allowable power rating and in observing the condition of the reactor, in much the same way that the temperatures and pressures in the combustion chambers of an internal-combustion engine are related to its power rating and condition. Clever means such as temperature-sensitive paints and piezoelectric pressure detectors have been devised for internal-combustion engines, and similarly clever means of detection eventually must be worked out for the reactor.

FLOW. Operation of the experimental reactor will involve a wide range of coolant flow rates. This makes it difficult to measure flow with fixed-orifice flowmeters.

Flow of liquid-metal coolant may be measured over a wide range by electromagnetic flowmeters.[1] This type of flowmeter has the great advantage that it does not require penetration of the pipe wall or introduction of fixed or moving devices into the coolant stream.

The electromagnetic flowmeter, Fig. 2, involves a permanent magnet to produce magnetic flux through the liquid metal flowing in the pipe. Motion of the conducting liquid metal in the magnetic field causes an electric potential gradient normal to the magnetic field and direction of flow. This potential is measured by means of electrodes attached to the pipe. For a given magnetic field, the potential measured is proportional to the flow of liquid, provided the flow is only a function of radius in the pipe.

There is considerable practical difficulty in calibrating any type of liquid-metal flowmeter for the large flows and high temperatures encountered in the power plant, so for some time to come the calibration of these meters may be by extrapolation from calibrations of small meters. However, the device has good sensitivity and stability when changes in magnetic field and electrical conductivity due to temperature are taken into account. It is believed that the magnetic field will not be affected appreciably by irradiation of the magnet.

LIQUID LEVEL. It is necessary to detect the level of the liquid-metal coolant in storage tanks, surge tanks, and in a number of other locations. Level indicators which involve transmitting motion or force from a float through the wall of the vessel are thought to be of questionable reliability if they involve immersed moving parts, thin diaphragms, or bellows.

Electrical contacts through which the liquid metal closes an electric

[1] "An Alternating Field Induction Flow Meter of High Sensitivity," by Alexander Kolin, *The Review of Scientific Instruments*, vol. 16, May, 1945, pp. 109-116.

circuit upon attaining a certain level may be used in some locations. These have the possible difficulty that condensing metal vapor may, in time, short-circuit insulation of the contact. Other means, utilizing electrical properties of the liquid metal, may be developed.

LEAK DETECTION. It is vitally important that leaks in the liquid-metal system be detected and located at their very incipience. Means for doing this usually involve detecting the metal vapor. The mercury-vapor detector[2] used in coal-fired mercury boilers is an example of this type of detection. In the atomic power plant the problem is considerably more difficult in the radioactive zone. It is not possible to locate the leak by inspection, once it has been detected; so there must be compartmentation of the space around the liquid-metal system, and numerous leak detectors to permit localizing the source of trouble.

OPTICAL SYSTEMS. There must be optical systems for viewing locations which are inaccessible because of radiation. Conventional glass mirrors and lenses are blackened in time by exposure to radiation, and plastic lenses cannot withstand the high temperatures, so optical systems must employ polished metal reflecting surfaces where exposed to radiation and heat in and around the reactor.

[2]"Industrial Mercury Vapor Detector," by T. T. Woodson, *Industrial Medicine*, vol. 10, April, 1941, pp. 22-24.

Atomic Fissions

News From The Atomic World

Research on Ship Propulsion Reactor Well Advanced

The Argonne National Laboratory and the Westinghouse Electric Corp. are engaged in the development of a land-based prototype of a reactor suitable for ship propulsion. Although this reactor, like the experimental breeder reactor and the materials testing reactor, will be built at the Nuclear Reactor Testing Station in Idaho, the engineering and development work is being carried out at Argonne and in the new laboratory of the Westinghouse Atomic Power Division on the site of the old Bettis Airport near Pittsburgh. Construction of the new laboratory was begun in July, 1949, and is scheduled for completion by next summer. Present obligations under the Westinghouse contract are approximately $6,000,000, of which about $2,600,000 is for operating costs and $3,400,000 for capital construction costs and equipment.

Research and development work is well advanced, and detailed engineering design of the ship propulsion reactor is scheduled to begin in about a year. Construction should be underway by 1952. Although cost estimates cannot be made until detailed design specifications have been completed, it is expected that the reactor will cost at least $25,000,000, and perhaps substantially more, depending upon the solutions found possible for the technical problems encountered.

The ship propulsion reactor will be a single purpose machine designed specifically for the purpose of producing large amounts of heat under conditions that will permit conversion to power for propulsion of naval vessels.

Construction of Intermediate Power Breeder Reactor to Begin Early 1950

Engineering design work on the Intermediate power breeder reactor, planned for construction at the West Milton, N. Y., site of the Knolls Atomic Power Laboratory near Schenectady, is being carried forward to permit a firm estimate of construction costs to be made. Preliminary site work, now underway, is expected to be completed in time for construction of major facilities to begin as early as possible in the 1950 construction season.

The Knolls reactor is designed to produce significant amounts of electric power utilizing neutrons in the intermediate energy range, and to investigate the possibilities of breeding fissionable material at the same time. If successful in both, this reactor would represent a major step forward in the direction of the production of useful power without depleting—and perhaps even increasing—the national supply of fissionable material. To date, no reactor has been built to operate in the intermediate energy range. Like the experimental breeder reactor, the heat energy of the intermediate reactor will be removed by means of liquid metal. This heat will then be used to generate power through conventional means. The Knolls reactor is expected to have an eventual cost of from $25,000,000 to probably as much as $40,000,000, depending upon the technical problems encountered.

AEC Authorizes 200 lbs. of Uranium Metal for Domestic Use

The AEC has authorized the production of 200 pounds of uranium metal for use under AEC license in non-Commission research projects in the United States. The metal will be specially produced and fabricated in the form of rods by the Mallinckrodt Chemical Works, St. Louis, Missouri. It will be made available by Mallinckrodt through normal commercial chemical channels. The retail price will be approximately $50 per pound.

The uranium metal to be made available is highly refined by ordinary standards and will be valuable for metallurgical studies and other general research uses. However, it will not have the extreme purity required for nuclear reactors and certain specific types of Atomic Energy research.

Inquiries concerning the availability of uranium metal for research purposes should be directed to:

Licensing Division, U. S. Atomic Energy Commission, New York Operations Office, Post Office Box 30, Ansonia Station, New York 23, N. Y.

Uranium metal was considered a laboratory curiosity prior to 1942 when total world production was less than 100 pounds. It has a density of 18.7 (18.7 times heavier than water), is ductile, (capable of being molded or worked) and is about as hard as iron. Silvery in color, uranium metal rapidly combines with oxygen so that upon exposure to air it becomes bronze in color, eventually turning to dull black.

New Gaseous Diffusion Plant

With construction well underway on K-29, the third in a series of gaseous diffusion units for production of Uranium-235 in the Oak Ridge area, the Atomic Energy Commission announced that the Maxon Construction Co., Inc., of Dayton, Ohio, had been approved as construction contractor and Giffels & Vallet, Inc., of Detroit as architect-engineer for

the building of a fourth gaseous diffusion unit, K-31, which will cost approximately $162,000,000.

The Maxon Co. and Giffels & Vallet already are engaged in the building of K-29, a $66,000,000 project. The Carbide and Carbon Chemicals Corp., operator of the present gaseous diffusion units, K-25 and K-27, is responsible for process development and process design for both K-29 and K-31 and for procurement of special production equipment and materials.

The Commission states that with preliminary design work already accomplished, preliminary construction work began in December, for K-31, which will be situated in the same general area as the other gaseous diffusion plants. As continuations of the gaseous diffusion process and with the same general design, both K-29 and K-31 will contribute to increased production of Uranium-235.

Other firms engaged in building the K-29 plant are Sargent & Lundy of Chicago, which is designing alterations in the electrical distribution system in the K-25 area; Kaighin and Hughes of Toledo, Ohio, mechanical subcontractors under Maxon; and Edenfield Electric Co. of Nashville, Tennessee, electrical sub-contractor under Maxon.

New Books on Atomics

Cosmic Ray Physics. By D. J. X. Montgomery. First edition. 6½ by 9¼, 370 pages, illustrated, cloth. Published by Princeton University Press, Princeton, N. J., 1949. Price $5.00.

From all directions in outer space the primary radiation impinges on air molecules at the top of the earth's atmosphere, at the rate of about one particle per square centimeter every three seconds at latitudes far from the equator, and at about one-tenth this rate near the equator. The intensity does not vary with time by more than a few tenths of a per cent. The incident particles, presumed to be protons, range in energy from a few billion electron volts up to possibly 10^{17} electron volts. Every second of every minute, every hour, day after day, year after year, century after century, they come, never stopping, never ceasing. These are the cosmic rays. Where they come from no one knows, nor why, but for some fifty years, now, they have intrigued men's minds and today, they are the subject of world-wide investigation.

During the last two decades a great deal has been written about these mysterious rays, many theories have been advanced to account for their existence. These rays represent the highest concentrations of energy that we know in the universe. Our most powerful accelerating equipment cannot even approach the energies of these rays which come to us from outer space. The accompanying photograph shows what happens when one of these particles hits the nucleus of an atom. This picture, taken from Mr. Montgomery's book

Any book described in this department may be purchased from the Book Department, ATOMICS, Technical Publishing Company, 53 W. Jackson Blvd., Chicago 4, Illinois

shows the almost complete disintegration of a silver nucleus in the photographic emulsion of a sensitive plate. In this "star" there are 34 visible tracks, primarily protons and alpha particles. The total energy of all the emitted particles probably exceeds 1000 Mev.

The particular value of the excellent book lies in the fact that between its covers is presented an up-to-date survey of the entire field of cosmic ray studies. Its intention is to afford a student an opportunity to gain expeditiously a knowledge of this specialized field sufficient to provide an overall view of the subject and to help him in his study of the literature on the subject. While the emphasis is on the experimental aspects of cosmic ray technique, it is not a handbook for the laboratory. Little description of electronic circuits or

equipment is included. Nor is it definitely historical; a considerable amount of historical material is included, this data is representative and in no way intended to be exhaustive. It is, however, an excellent survey and there is much in it to indicate promising lines of attack for the future.

Dr. Montgomery is now conducting cosmic ray research at the Aberdeen Proving Ground in Maryland. He has specialized in cosmic ray work for many years and during the writing of this book consulted with leading workers in the field in the United States and Europe. The book had its inception in a series of lectures given at Princeton University in the spring of 1946 by Marcel Schein of the University of Chicago. A set of notes for these lectures was prepared and distributed under the auspices of Palmer Physical Laboratory. Through the support and encouragement of Professor John A. Wheeler of Princeton, it was possible for Dr. Montgomery to begin the expansion of these lecture notes into the book during his affiliation with Princeton University.

Nine Volumes of Nuclear Energy Series Published

The U. S. Atomic Energy Commission announced today that nine volumes totaling 5428 pages of the National Nuclear Energy Series—a comprehensive record of the non-secret scientific achievements of the wartime and post-war atomic energy programs—have been published to date, and two additional volumes will be available within the next few days.

The National Nuclear Energy Series, which has been described as the largest single venture in photo offset publication of scientific texts ever undertaken, is being published by the McGraw-Hill Book Company under a contract with Columbia University, which represents the AEC and its research contractors.

The NNES material, which may run to about 50 or more unclassified volumes, describes work in physics, chemistry, metallurgy, engineering, biology, medicine and many other fields related to atomic energy. The volumes are being written and edited for the most part by the specialists who performed the original research. The first volume, entitled "Histopathology of Irradiation from External and Internal Sources," was published in December, 1948.

The work of preparing the NNES manuscripts for printing is performed by the AEC Technical Information Branch at Oak Ridge, Tenn. The Branch also prepares drawings, diagrams and other illustrative material. The volumes are lithoprinted by Edwards Brothers of Ann Arbor, Mich., and sold by McGraw-Hill.

The nine volumes published to date are:

Histopathology of Irradiation from External and Internal Sources. Edited by William Bloom, M.D.; 808 pages. This is an advanced treatment of the histopathological and cytological effects of total-body irradiation by radioactive agents.

Pharmacology and Toxicology of Uranium Compounds. Edited by Carl Voegtlin and Harold C. Hodge; 1,084 pages. A summary of approximately three years' work on the toxicity of uranium compounds and the mechanism of uranium poisoning. The book also includes a section on the toxicity of fluorine and hydrogen fluoride.

Engineering Developments in the Gaseous Diffusion Process. Edited by Manson Benedict and Clarke Williams; 129 pages. This volume sets forth the research and engineering developments pertaining to novel auxiliary devices developed in connection with the gaseous diffusion plant. The work applies principally to special plant instruments, vacuum engineering, development of heat-transfer equipment, and absorption of uranium hexa-fluoride and fluorine.

Spectroscopic Properties of Uranium Compounds by G. H. Dieke and A. B. F. Duncan; 290 pages. This volume presents a most comprehensive correlation of absorption measurements with fluorescence spectra data. New experimental techniques described represent advances in organic chemistry.

Bibliography of Research on Heavy Hydrogen Compounds. Compiled by Alice H. Kimball, edited by Harold C. Urey and Isadore Kirschenbaum; 350 pages. A compilation of about 2,000 references to published documents dealing with research on the heavy hydrogen isotopes is given in this book. As a bibliography of such research, the volume constitutes a useful tool for any scientist interested in isotope research.

Ionization Chambers and Counters: Experimental Techniques by Bruno Rossi and Hans Staub; 243 pages. The volume discusses the modern principles of ionization chambers and counters, and presents details of a number of detectors developed and used at the Los Alamos Scientific Laboratory for the study of different kinds of radiation.

Any book described in this department may be purchased from the Book Department, ATOMICS, Technical Publishing Company, 53 W. Jackson Blvd., Chicago 4, Illinois

Electronics: Experimental Techniques by W. C. Elmore and Matthew L. Sands; 417 pages. As a description of the most useful circuits for making nuclear and other physical measurements, this volume constitutes a manual of the circuit elements and complete circuits for electronic instruments.

The Transuranium Elements Research Papers. Edited by Glenn T. Seaborg, Joseph J. Katz, and W. M. Manning; 1,733 pages. This work consists of over 150 original research papers on the transuranium elements, neptunium, plutonium, americium and curium, and cognate topics. The authors have included a historical discussion of the research work for reference and orientation purposes.

The Characteristics of Electrical Discharges in Magnetic Fields. Edited by A. Guthrie and R. K. Wakerling; 376 pages. This volume covers most of the significant studies on the characteristics of electrical discharges in magnetic fields carried by the University of California Radiation Laboratory in connection with the development and operation of the electromagnetic process for the separation of U-235. Primary emphasis is placed on studies of electrical discharges in the vapors of uranium compounds. The information included is considered to be an important contribution to the understanding of the theory of gaseous discharges.

The two volumes scheduled for publication within the next few days are:

Vacuum Equipment and Techniques. Edited by A. Guthrie and R. K. Wakerling; 264 pages. This volume is a compilation of observations made by the University of California Radiation Laboratory personnel in the course of developing high vacuum equipment for use in the electromagnetic separation plant. The requirements for routine production and maintenance of high vacuum on a scale never previously undertaken necessitated considerable pioneering work on both equipment and testing.

The Chemistry and Metallurgy of Miscellaneous Materials. Thermodynamics. Edited by Laurence L. Quill; 329 pages. Ten original papers on thermodynamic properties of the elements and several of their compounds are presented in this volume.

Guide for AEC Contracting of Construction

A U. S. Atomic Energy Commission booklet entitled "A Guide for Contracting of Construction and Related Engineering Services," which describes how AEC construction and architect engineer contracts are awarded, has been placed on sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. for a price of 10 cents.

The booklet contains information on the various types of contracts used by the AEC, including lump-sum, fixed-price and cost-plus-a-fixed-free contracts, and describes the steps firms should take to be considered for those types of work where bids cannot be solicited by formal advertising.

The basic AEC contracting policies affecting construction and engineering services are described in the booklet as follows:

1. To the fullest extent feasible, construction contracts are made on a lump-sum or unit price basis using formal advertising procedures.
2. Where formal advertising cannot be used, as full and free competition as is feasible is obtained to secure the required services.
3. Special effort will be made to place contracts with small-business concerns competent to perform satisfactorily.

Last August the AEC published a booklet entitled "Contracting and Purchasing Offices of the Commission and the Types of Commodities Purchased," which also provides information of interest to firms wishing to do business with the AEC. It is also available from the Superintendent of Documents for a price of 10 cents.

The Atomics Bookshelf

Introduction to Radiochemistry. By Gerhart Friedlander and Joseph W. Kennedy. John Wiley & Sons, Inc. $5.00

An excellent, up-to-date book describing the nature and applications of radioactivity without assuming previous knowledge of nuclear physics. It begins with a brief discussion of the historical background which is used as an introduction to the early chapters on descriptive information about atomic nuclei, nuclear reactions, and the apparatus used for the acceleration of nuclear projectiles. Later chapters discuss all aspects of nuclear phenomena.

Radioactive Tracer Techniques. By Geo. K. Schweitzer and Ira B. Whitney. D. Van Nostrand Co. $3.85

A useful manual designed to serve as a guide for laboratory work and instruction in the use of radioactive tracers. It should be of value to all who may have use for radioactive isotopes as tracers in industrial or medical applications.

The Universe and Dr. Einstein. By Lincoln Barnett with an introduction by Albert Einstein. William Sloan Associates. Price $2.50

A brilliant attempt, a very successful attempt in fact, to describe the universe as it now appears in the light of modern scientific theory. This is a universe, as Mr. Barnett shows, of atoms, electrons and energy quanta. Despite the abstruse nature of the subject this is a book which the intelligent layman can read, indeed, it was for the layman that the book was written. The foreword by Dr. Einstein himself gives authenticity to Mr. Barnett's work.

Atomic Energy. By Karl K. Darrow. John Wiley & Sons, Inc., $2.00

The exciting story of the development of nuclear physics—a story climaxed by the reality of atomic energy and the atomic bomb. Told by an expert who can speak the layman's language.

Elementary Nuclear Theory. By H. A. Bethe. John Wiley & Sons, Inc., $2.50

A short course on selected topics for those who are seriously interested or concerned with nuclear physics. It is a course given at the Research Laboratory of the General Electric Co. at Schenectady, N. Y. This is not a book for beginners.

Atomic Energy in Cosmic and Human Life. By George Gamow. The MacMillan Co., $3.00

A fascinatingly simple book for beginners but equally interesting to those who already know something about the subject. Written in Dr. Gamow's inimitable style.

Any book described in this department may be purchased from the Book Department, ATOMICS, Technical Publishing Company, 53 W. Jackson Blvd., Chicago 4, Illinois

Applied Nuclear Physics. By Ernest Pollard and William L. Davidson. John Wiley & Sons, Inc., $3.00

The best book of its kind. Designed for the serious student, much of the book is understandable to those who have little background in the field of nuclear physics. Its aim is to be of definite service to chemists, biologists, physicians and engineers who though not necessarily versed in the language of physics, are using the products of nuclear physics to further their ends in their own spheres.

The Atomic Story. By John W. Campbell. Henry Holt & Co., $3.00

By all odds the best and most interesting book on atomic energy for the layman. Written by a man who possesses the unique combination of writing ability and technical knowledge, it is first of all a story, not a treatise. At the same time it is accurate. It is the most important story of our time told in simple language by a man who has spent many years in the field of science fiction. He is the Editor of Astounding Science Fiction.

The Strange Story of the Quantum. By Banesh Hoffman. Harper & Brothers, $3.00

Easily the best account of the growth of the ideas underlying our present knowledge of atomic structure, prepared for the reader not especially trained in nuclear physics. It has taken one of the most abstruse and difficult questions—just how matter and energy are put together—and made it readable and understandable as it can be.

No Place to Hide. By David Bradley. Little Brown & Co., $2.00

A straight down-to-earth description of what an atomic bomb can do to ships, islands, seaports, harbors—and thereby to human beings. The author was a radiological monitor with the task force that made the Bikini tests. in this little book he gives a day-by-day account of the operation, seen not through the eyes of an expert, but by a doctor particularly interested in finding out the bomb's immediate and after effects on people.

The Science and Engineering of Nuclear Power. Two Volumes. Edited by Clark Goodman. Addison Wesley Press, Inc., $7.50 each

These two volumes contain the essentials of a series of seminars initiated at MIT in October 1946. They provide, by far, the most valuable and usable technical material for the engineer available today. Their objective is to present the fundamentals of chain reacting systems in terms that are understandable to engineers interested in the industrial applications of nuclear energy.

Fear, War, and the Bomb. By P. M. S. Blackett. Whittlesly House, $3.50

Written by a 1948 Nobel Prize winner, this dynamic, hopeful and authoritative analysis of our atomic future has aroused world-wide attention. According to Professor Blackett, the world today has an atomic neurosis. We are handcuffed by fear. Without ever underestimating the impact or importance of atomic energy, Professor Blackett challenges many of the dire predictions that have been made since the atomic bombs were exploded over the Japanese cities in the summer of 1945.

Must We Hide. By E. R. Lapp. Addison-Wesley Press, Inc., $3.00

A book which points up *facts* about atomic weapons and views them in realistic terms, attempting neither to depreciate nor to exaggerate the effects to American cities. It points out which of our cities are the most vulnerable and what defenses may be prepared against possible future attacks. A most interesting book for the layman—understandable and stimulating.

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